# INVESTIGATION OF A QUASI-HOLOGRAPHIC SYNTHETIC-APERTURE ACOUSTICAL IMAGING SYSTEM

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# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

# THESIS

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Synthetic-Aperture Acoustical Imaging System

by

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# Investigation of a Quasi-Holographic Synthetic-Aperture Acoustical Imaging System

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## ABSTRACT

A side-looking sonar system which utilizes coherent electrical processing is investigated. Such a system produces a quasi-hologram of the reflected sound field which may be subsequently imaged to give a visual presentation of the insonified region.

An actual working laboratory system is constructed and several quasi-holograms are depicted in the Data and Results section. Imaging is not completed, however, an optical processing arrangement to accomplish this task is presented.

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# I. INTRODUCTION

Conventional methods of imaging sound which is dispersed by an object are generally of three classes. /Ref. 1/ The first method is through the use of a pulse-echo system in which a stationary hydrophone array is utilized to discretely sample an acoustic plane. This information is subsequently used to produce an acoustic hologram. The main problem with this system is that for frequencies at which reasonable ranges can be expected, the size of the hydrophone arrays for adequate resolution becomes prohibitively large.

Secondly there is the pulse-echo system currently employed in most present day sonars in which the returned echo's intensity is detected in azimuth and time, relative to the insonifying pulse, and is displayed on a range and azimuth presentation system such as a cathode ray display. In this system the phase information of the returned signal is not used, thus all objects whose reflected sound intensity are the same image identically. The reliability of the pulse-echo technique is generally recognized to be quite limited, especially for identification and classification of objects.

The third general class of sound imaging systems are direct image forming in which an acoustical lens is used to form an acoustical image which may in turn be transformed into a visual image by various techniques. Depth of focus, depth of field, and angular field of view are all limited in this system. In practice the building of a sufficiently wide aperture focusing system to be used with acoustical waves of the order of 5000 Hz is prohibitively large and expensive.

This thesis concerns itself with experimental investigation of a method of acoustical image recording in which a modifed form of holographic imaging is combined with resolution enhancement made possible by a synthetic-aperture approach to sound field sampling. [Ref. 2]

If a sonar is of the conventional variety, then its azimuthal resolution in the best possible case is diffraction limited. In this best of all possible cases, which in practice is seldom realized, the resolution at any range R is of the order of $R\lambda/D$ where $\lambda$ is the wavelength and D is the hydrophone dimension in the azimuthal plane. Because sonar wavelengths for which appreciable ranges may be achieved are many orders of magnitude larger than optical wavelengths very large values of D must be used if resolutions comparable to normal visual systems are to be realized. If one wishes to have even roughly comparable azimuthal resolution hydrophone arrays of the order of thousands of feet would be necessary. Obviously it is impractical to carry arrays of this size on conventional ships.

A synthetic-aperture sonar imaging system offers a partial solution to this problem. It is possible to install aboard a ship a small transducer oriented so that it projects and listens to the side with a relatively wide beam sound pattern. This transducer is consecutively carried to a sequence of positions determined by the ship's track. Each of these positions may be treated as if they were the positions of individual transducer elements in a linear array. [Ref. 3] At each position the transducer radiates a pulse and then receives and stores the reflected signal for subsequent image processing. These processed signals are similar to those which would be achieved if a large linear array were utilized and thus the angular resolution and the signal-to-noise ratio are improved.

Another one of the unique advantages of using a holographic system is its depth of focus characteristics. /Ref. 1/ In a normal imaging system the turbidity between the viewing plane and the object produce defocused images of the sources of turbidity which affect resolution and clarity of the object. In extreme situations turbidity may be the predominant range limiting factor. The analogous analysis in a sonar medium has the turbidity represented by suspended particles and other reverberation centers which produce cognate defocused images of the scattering centers. The depth of field of a hologram, which in theory is infinite /Ref. 2/, incorporates a means of eliminating this problem. Scattering centers suspended in the medium will have one of two effects: (1) if they are static particles they will register their own holograms and thus reconstruct in space without interfering with the object under study, which is fixed in depth of view by the limitations of the viewing system; or (2) if dynamic, the particles will produce a uniform background illumination superimposed on the object hologram which will, provided the recording system's response remains in its linear region, have no effect on the reconstruction of the target image.

## II. THEORY

In the recording of a side-looking sonar for subsequent quasi-holographic imaging a pulsed transmission, whose frequency is accurately controlled by a continually active stable master oscillator, is used to periodically insonify the region of interest. The reflected signals are detected at the receiving hydrophone and the electrical output from this receiving hydrophone is directed to one of the inputs of a summing network where it is summed with the output of the master oscillator. It is the output of this summing network which is essentially the holographic information since it consists of a signal which contains in its amplitude envelope the phase and intensity of the sampled return echo.

In order to image this information it is necessary to record the holographic data for subsequent visual reproduction of the generated sound field which is sampled along the trajectory which the hydrophone transits.

For this experiment the output of the summing network was used to intensity modulate the output of a cathode ray tube which was in turn made to sweep in time during the listening cycle of the holographic recording. This sweeping in time thus furnished range information during its sweep period. Azimuthal information was displayed by varying the horizontal position of the sweep to correspond to a given position in the recording hydrophone trajectory.

A simplified block diagram of this system is depicted in Fig. 1 and a general functional description follows:

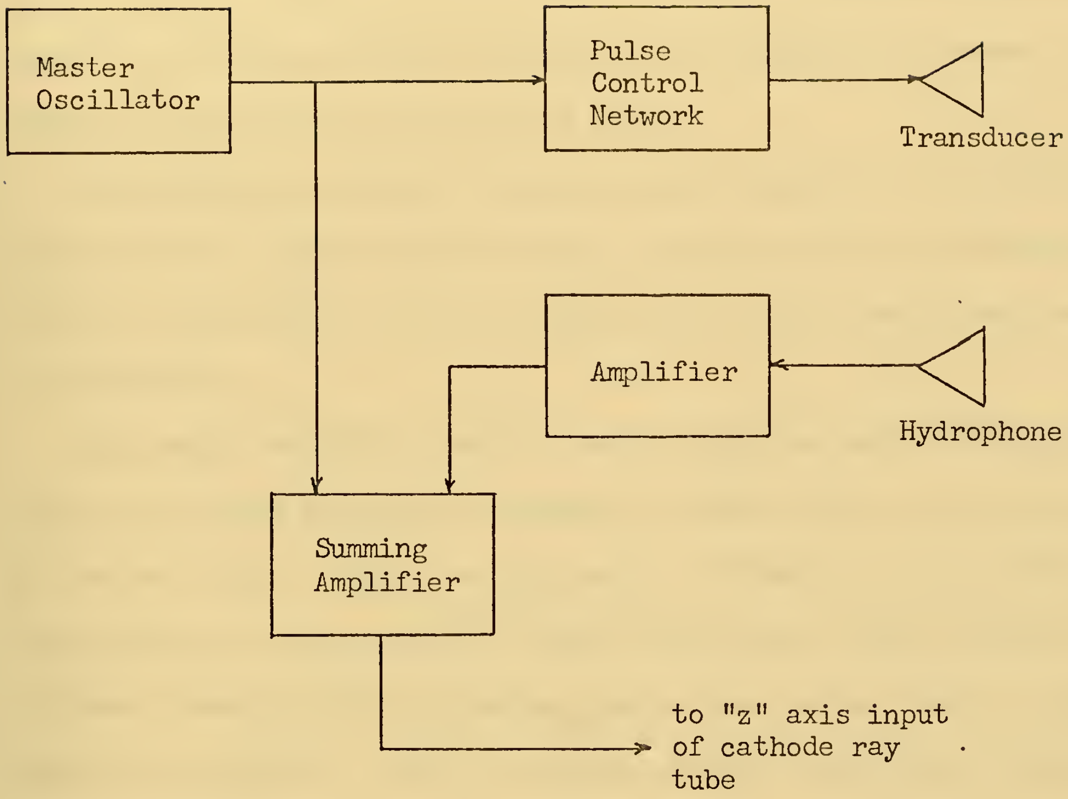


Figure 1. Block diagram of pulse/receive system

The master oscillator was used as a source for a highly stable sinusoidal voltage reference. It was connected to the pulse control network and to one of the inputs of the summing amplifier.

A gated pulse output for this system was provided by the pulse control network. This network was utilized to provide a method of periodically providing to the transducer the sinusoidal voltage produced by the master oscillator. The transducer thus produced a pulsed pressure wave which was coherent with the output of the master oscillator. In addition the pulse control network provided a gating signal which drove the vertical sweep of the cathode ray tube. This gating

signal was suitably delayed to allow the vertical sweep of the cathode ray tube to commence immediately after the termination of the transmitted signal. This was done in order that the recorded information would only be that part which contained the information inherent to the reflected signals from the field of view.

The hydrophone amplifier served the dual purposes of isolating the hydrophone from the master oscillator voltage output and providing the necessary amplification of the comparatively weak signals received from the hydrophone.

The summing amplifier receives inputs from the master oscillator and the receiving hydrophone yielding an output which is the linear sum of the two inputs. Since the fundamental frequency of the summing amplifier inputs is generated by a stable oscillator, whose coherence time is large compared to the coherence time of the system, the two input signals are coherent. Thus the summing network output may be represented by

$$\psi_{SA} = \mathcal{R}e \left\{ \left[ A + A' e^{j\varphi} \right] e^{j\omega t} \right\}$$

Where $\psi_{SA}$ is the signal output of the summing amplifier, $\mathcal{R}e\left[A e^{j\omega t}\right]$ is the input from the master oscillator, $\mathcal{R}e\left[A' e^{j(\omega t + \varphi)}\right]$ is the input from the hydrophone, $A$ and $A'$ are the amplitudes of the reference and hydrophone respectively, $\omega$ is the radian frequency of the signal, $t$ represents time, and $\varphi$ is a phase factor introduced into the returned signal by target reflection parameters and range. It should be noted that in general $A'$ and $\varphi$ are functions which depend upon target range, target surface characteristics, and time. For this experimental set up $A$ and $\omega$ were controlled constants.

The output of the summing amplifier is used to intensity modulate a cathode ray tube whose output is in turn recorded by photographic film. The film, if properly exposed, can be made to respond linearly to intensity. It is possible, under these circumstances, to analyze the image recording and reproduction by quasi-holographic considerations. For examination of the signal recording process consider the experimental geometry as depicted in Fig. 2.

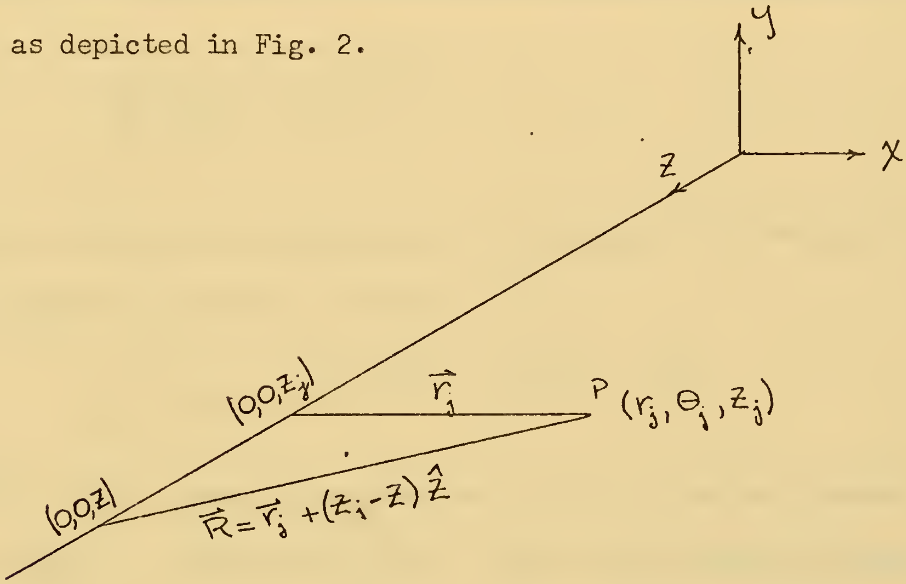


Figure 2. Recording geometry

Since it is possible to consider any object as a composite of high density point scattering centers [Ref. 4] we will consider, for simplicity of analysis, the recording of an individual point scattering center located at the point P given in cylindrical coordinates ( $r_j$ , $\theta_j$ , $z_j$ ). The transducer/hydrophone transit is restricted to a space trajectory coincident with the z axis of the coordinate system. For the following discussion it is assumed that the transducer/hydrophone assembly is capable of transiting a trajectory exactly coincident with the z axis.

In practical situations, such as a ship at sea which cannot steer a straight course to this required accuracy, this is an impossible limitation to satisfy. However, it would be possible to provide an inertial correction to the reference signal which would overcome this limitation.

The reference or master oscillator produces sinusoidal output of radian frequency $\omega$ which may be represented by the real part of [Ref. 5]

$$\psi_r(t) = A e^{j\omega t}$$

The signal return to the hydrophone from the point scattering center may be represented by the real part of

$$\psi_p(t, R) = A' e^{j\left(\omega t - \frac{2\omega R}{u} + \varphi\right)}$$

where $A' e^{j\varphi}$ is the complex amplitude which will in general depend upon such things as: transmitted power, target reflectivity and phase shift, and signal propagation attenuation; R is the range of the point scattering source from the transducer/hydrophone location; and $u$ is the speed of sound in the medium.

If $(0, 0, z)$ is taken to be the coordinate of the transducer/hydrophone at any given time then the range R may be expressed as

$$R = \sqrt{r_j^2 + (z - z_j)^2}$$

$$= r_j \sqrt{1 + \left(\frac{z - z_j}{r_j}\right)^2}$$

Therefore the returned signal may be written[1]

$$\psi_p(t,z) = \left(A' e^{j\varphi}\right) e^{j\left\{\omega t - \frac{2\omega r_j}{u}\left[1 + \left(\frac{z - z_j}{r_j}\right)^2\right]^{1/2}\right\}}$$

We now make the assumption that $r_j$ is greater than ( $z - z_j$ ). This assumption is justified in most applications of a side-looking sonar where the transducer/hydrophone transits a path whose length is large compared to the range of the targets of interest. With this assumption and neglecting terms of higher order than two

$$R = r_j\left[1 + \left(\frac{z - z_j}{r_j}\right)^2\right]^{1/2}$$

$$R \cong r_j + \frac{(z - z_j)^2}{2 r_j},$$

therefore the returned signal may be written

$$\psi_p(t,z) = \left(A' e^{j\varphi}\right) e^{j\left[\omega t - \frac{2\omega r_j}{u} - \frac{\omega (z - z_j)^2}{u r_j}\right]}$$

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[1] In the following discussion the real part of the exponential notation will be assumed

From the geometry of Figure 2 it is seen that

$$r_j = \sqrt{R^2 - (z - z_j)^2}$$

However range R as a function of time is given by

$$R = \frac{ut}{2}$$

and therefore we may write $r_j$ as

$$r_j(t,z) = \sqrt{\frac{ut}{2} - (z - z_j)^2}$$

Utilizing this representation for $r_j$ the returned signal may be written

$$\psi_p(t,z) = \left(A' e^{j\phi}\right) e^{j\omega\left[t - \frac{2\sqrt{\left(\frac{ut}{2}\right)^2 - (z-z_j)^2}}{u} - \frac{(z-z_j)^2}{u\sqrt{\left(\frac{ut}{2}\right)^2 - (z-z_j)^2}}\right]}$$

This returned signal furnished one of the inputs of the summing amplifier network where it was summed with the reference signal. Thus the output of the summing network, which was used to intensity modulate the cathode ray beam, may be represented by

$$\psi_{SA} = \psi_r + \psi_p$$

$$\psi_{SA} = A e^{j\omega t} + \left(A' e^{j\varphi}\right) e^{j\omega\left[t - \frac{2r_i}{u} - \frac{(z - z_i)^2}{2r_i}\right]}$$

In this experiment z, the transducer/hydrophone position, was controlled and made proportional to the horizontal position of the cathode ray trace. (Fig. 3)

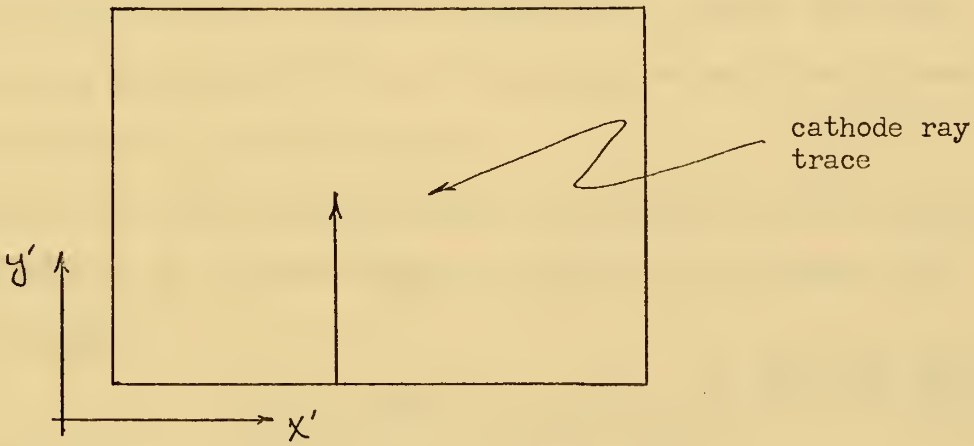


Figure 3. Cathode ray trace geometry

$$x' = \alpha z$$

$$y' = \beta R = \frac{\beta u t}{2}$$

where $\alpha$ is the azimuthal scaling factor and $\beta$ is the range scaling factor.

As can be seen in Fig. 3 the vertical position $y'$, which is swept in time, is a scaled function of the target range.

Since vertical position represents successive ranges and since the speed of sound in a homogeneous medium is isotropic in general, a signal received at the hydrophone at time t and displayed as an intensity at vertical position $y'$, represents the locus of points which satisfy the relationship R=Ut/2. Thus as a signal is received and displayed utilizing this technique the target point scattering locations $z_j$ are effectively integrated over all values which satisfy the relation

$$R_{MIN} \leq z_j \leq R_{MAX}$$

where $R_{MIN}$ is that minimum range determined by the time at which the receive cycle is started and $R_{MAX}$ is determined by that time represented by the termination of a vertical sweep.

Utilizing this criteria and assuming a sufficiently isotropic hydrophone beam pattern the intensity pattern produced by the cathode ray tube may be written

$$I(x',y') = I_o + \delta \left\{ A e^{j\omega\left(\frac{2y'}{\beta u}\right)} + \left(A' e^{j\varphi'}\right) e^{j\left[\omega \frac{2y'}{\beta u} - \frac{\omega 2 r_j'}{u} - \frac{\frac{\omega}{\alpha^2}(x'-x_j')^2}{r_j' u}\right]} \right\}$$

where $I_o$ is a biasing intensity introduced by the response of the electronics of the cathode ray circuitry preventing negative values of intensity, $A'e^{j\varphi'}$ is the complex target amplitude written as a function of $x'$ and $y'$, $x_j'$ corresponds to the target coordinate $z_i$ and is equal to $\alpha z_j$, $\delta$ is the cathode ray response coefficient which in this experiment is equal to one, and

$$r_j' = \sqrt{\left(\frac{y'}{\beta}\right)^2 - \frac{1}{\alpha^2}(x'-x_j)^2}$$

In the photographic reproduction a scaling factor is introduced. For most camera lens system this scaling is the same in all planar directions and the transformations are:

$$y'' = \kappa y' = \kappa \beta R$$

$$x'' = \kappa x' = \kappa \alpha Z$$

Where $\kappa$ is the scaling factor and $x'', y''$ are dimensions as measured in the focal plane of the camera lens system.

Using this notation and in addition stipulating that:

$$\omega' = \frac{2\omega}{u}$$

$$r_j'' = \sqrt{\left(\frac{y''}{\kappa\beta}\right)^2 - \frac{1}{\kappa^2\alpha^2}\left(x'' - x_j''\right)^2}$$

$$\sigma = A'' e^{j\varphi''}$$

(where the double prime implies that the equation has been rewritten as a function of $x''$ and $y''$) one may write the intensity function presented to the photographic plate for recording as

$$I(x'', y'') = I_0 + A e^{j\omega'\left(\frac{y''}{\kappa\beta}\right)} + \sigma e^{j\omega'\left[\frac{y''}{\kappa\beta} - r_j'' - \frac{(x'' - x_j'')^2}{2\kappa^2\alpha^2 r_j''}\right]}$$

Turning our attention to the imaging of the recorded data we will continue to limit attention to a single range $r_i$ thus consider only the data recorded along a line $y'' = y_i''$ depicted in Figure 4.

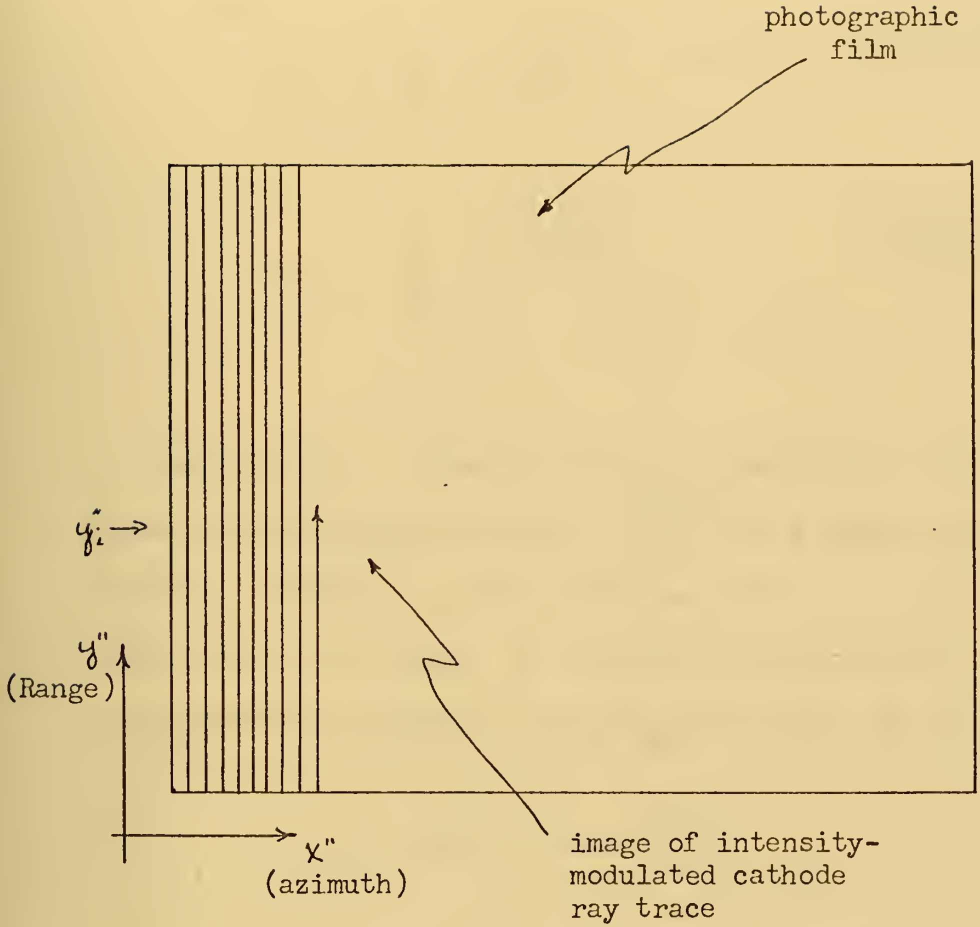


Figure 4. Photograph image plane geometry

By properly exposing the photographic plate to ensure linear transmittance response a photographic record is made with amplitude transmittance $T$ given by

$$T(x'', y'') = \Lambda \cos\left[\frac{\omega' y''}{\epsilon\beta} - \omega' r_i'' - \frac{\omega'(x'' - x_i'')^2}{2\epsilon^2\alpha^2 r_i''}\right]$$

where $\Lambda$ is a constant and the phasor notation has been dropped.

By decomposing the cosine into two complex exponential factors the transmittance $T$ may be expressed as the sum of two terms $T_r$ and $T_v$ where

$$T_r = \frac{\Lambda}{2} e^{j\left[\frac{\omega' y''}{\epsilon\beta} - \omega' r_i'' - \frac{\omega'(x'' - x_i'')^2}{2\epsilon^2\alpha^2 r_i''}\right]}$$

$$T_v = \frac{\Lambda}{2} e^{-j\left[\frac{\omega' y''}{\epsilon\beta} - \omega' r_i'' - \frac{\omega'(x'' - x_i'')^2}{2\epsilon^2\alpha^2 r_i''}\right]}$$

Examining $T_r$ term by term it is seen that $\omega' r_i''$ is a constant phase factor and may be ignored, $\frac{\omega' y''}{\epsilon\beta}$ is a phase term linear in $y''$ and thus introduces a tilt in the phase front of each component of transmitted light. The angle $\theta$ of tilt from the plane of the film transparency may be determined from the relationship [Ref. 5]

$$\sin\theta = \frac{\lambda_0 \omega'}{2\pi}$$

where $\lambda_0$ is the wavelength of the transmitted light.

In order to examine the last term we first note its similarity to the transmittance function $T_\ell$ of a positive cylindrical lens

$$T_\ell = e^{-j\frac{\pi}{\lambda_0 f_1} x^2}$$

where $f_1$ is the focal length.

A simple translation of coordinates allows this cylindrical lens to be centered at coordinate $x_i$. The corresponding transmittance function is

$$T_\ell = e^{-j\frac{\pi}{\lambda_o f_1}(x-x_i)^2}$$

Comparing this term with the final term of $T_r$ it is found that the film acts as a positive cylindrical lens with focal length $f_+$ given by

$$f_+ = \frac{\epsilon^2\alpha^2}{2}\left(\frac{\lambda_r}{\lambda_o}\right)r_i''$$

( $\lambda_r$ is the wavelength used to record the original hologram).

A similar argument for $T_v$ yields that it acts as if it were a negative cylindrical lens with focal length $f_-$ given by

$$f_- = -\frac{\epsilon^2\alpha^2}{2}\left(\frac{\lambda_r}{\lambda_o}\right)r_i''$$

In addition there is a tilt in the phase front in the opposite direction equal to $-\theta$ for this term.

Figure 5 illustrates the azimuthal images produced by a point scattering center. The two components $T_r$ and $T_v$ may be regarded as generating a real line-segment image focused at a distance $f_+$ behind the film transparency and a virtual line-segment image focused at a distance $f_-$ in front of the film transparency. The focusing of a point source to a line-segment image is caused by the finite pulse width of the transmitted signal which spreads the zone plate intercept of the hologram in the $y''$ or range dimension. Since the film exerts no focusing power in this dimension the size of the line segment is proportional to the pulse width of the transmitted signal.

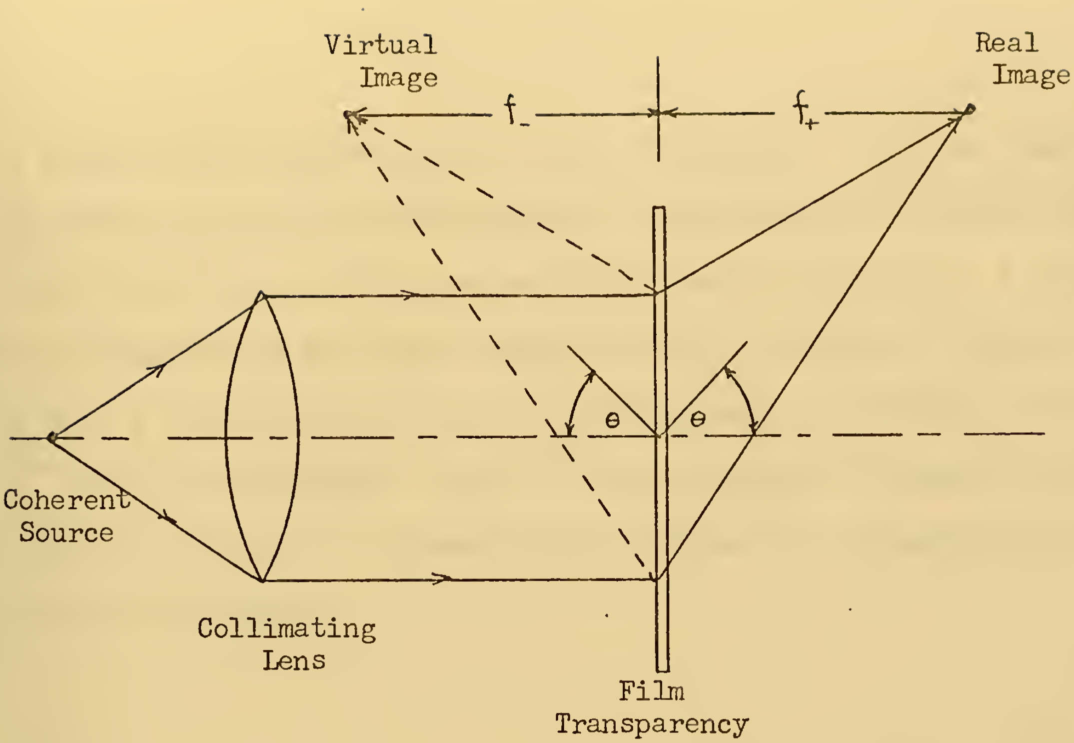


Figure 5. Film focal properties for azimuthal dimension.

In order to complete the imaging of the recorded information recall that the range information has been transferred to the $y''$ coordinate. Therefore in order to produce an image it is necessary to image the $y''$ variations of the film coincident with the loci of the azimuthal foci which are individually functions of range.

These imaging requirements can be accomplished with the optical system illustrated in Figure 6. A positive conical lens, whose transmittance is given by

$$t_c(x'',y'') = e^{-j\frac{\pi}{\lambda_o f_1} x''^2}$$

where

$$f_1 = \frac{\epsilon^2 \alpha^2}{2} \left( \frac{\lambda_r}{\lambda_o} \right) r_i''$$

is placed immediately behind the film transparency. This lens removes the entire tilted plane containing the virtual images to infinity while the $y''$ variations of film transmittance remain undistorted. A cylindrical lens placed one focal length from the film creates a virtual image of the $y''$ dimension structure at infinity where it coincides with the $x''$ dimension structure. Now it is only necessary to image an infinitely distant object; this is accomplished by the use of a spherical lens as depicted in Figure 6.

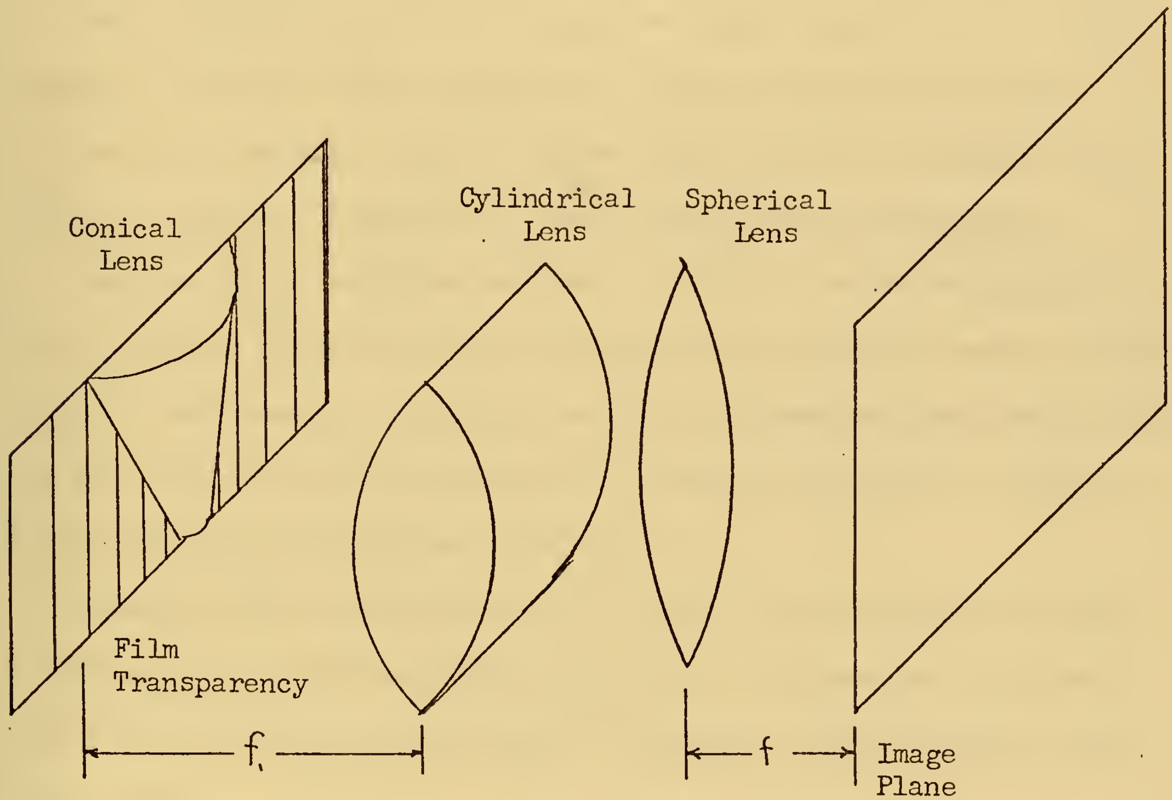


Figure 6. Optical imaging system.

## III. EXPERIMENTAL TECHNIQUE

For this experiment a transmitting, receiving, recording system as depicted in Figure 7 was fabricated utilizing standard laboratory apparatus.

The master oscillator, a RF Signal Generator Set AN/URM-25D which is rated accurate in operating frequency within 0.05%, was used as a source for the sinusoidal driving voltage and as the reference oscillator. This oscillator delivered an RMS voltage of 5 volts into a 50 ohm load providing ½ watt of electrical power to drive the transducer.

The oscillator's output was connected concurrently to: (1) the input of a General Radio Company type 1396-A Tone Burst Generator, (2) to the input of a Hewlett-Packard Model 355A VHF Attenuator, and (3) to a Computer Measurements Company Model 904 Counter/Timer.

The Tone Burst Generator was used to control the pulse output of the transducer which in turn was utilized to insonify the region of interest. Additionally a gating pulse which is produced concurrently with the start of the Tone Burst Generator output was utilized to trigger a Tektronix Type 565 Dual-Beam Oscilloscope.

A General Radio Company Type 1217-C Unit Pulse Generator provided a timing input to the Tone Burst Generator. This enabled the pulsed output to be accurately controlled in both pulse width and pulse repetition rate.

The receiving hydrophone was connected through a series of cascaded amplifiers to one input of the summing network. These receiving signal amplifiers consisted of one Hewlett-Packard 461A General Purpose Amplifier, having a gain of 40 db, and two Hewlett-Packard 467A Power

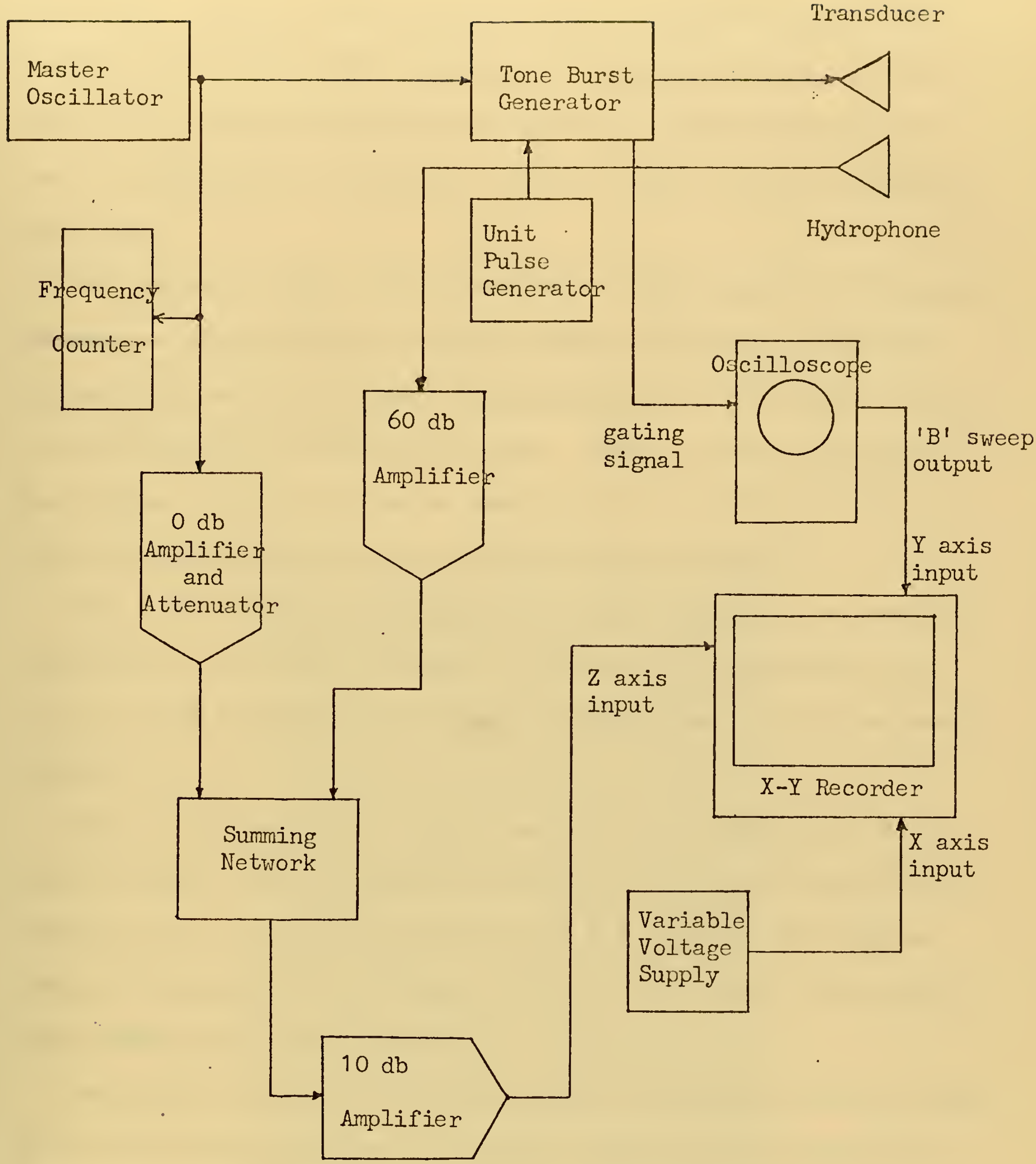


Figure 7. Transmitting, Receiving, and Display System block diagram.

Amplifiers. The total amplification of this configuration was 60 db. In addition to these cascaded amplifiers providing the needed amplification of the initial weak received signal they served the ancillary task of assisting in isolating the reference signal from the receiving hydrophone.

The reference signal, which provided the second input to the summing network, was first directed through a Hewlett-Packard Model 355A VHF Attenuator where it was reduced from approximately 7 volts peak to peak to approximately 0.05 volts peak to peak. This was done in order that the reference signal input to the summing network might match the nominal peak to peak voltage of the amplified returned signal.

With these inputs the summing network, whose output is the straight linear sum of its inputs, was made to vary between approximately -0.1 and +0.1 volts depending upon the phase correspondence of the two input signals.

From the summing network output the signal was amplified 10 db by a Hewlett-Packard 467A Power Amplifier and then directed to the Z axis or cathode control of a Hewlett-Packard 1300A X-Y Display. The cathode response bandwidth of this display is DC to 20 MHZ. with +1 volt giving full blanking and -1 volt giving full intensity.

The vertical sweep of the Hewlett-Packard X-Y Display was controlled by the "B" sweep output from the Tektronix 565 Dual-Beam Oscilloscope. The start of this sweep was delayed in time so that the sweep began immediately after the termination of each transmitted pulse. This was done so that the time during which the X-Y Display was sweeping would correspond to the receive part of the overall cycle. It is during this part of the cycle that the reflected sound waves which contain the

information available from the reflection of targets in the field of interest are incident upon the face of the hydrophone. It is this information which one wished ultimately to display visually. For this experiment the time duration of one vertical sweep was 3 milliseconds which corresponded to the time necessary for sound ranging to the furthest dimension of the test tank. Figure 8 shows the pulsed output of the Tone Burst Generator on the lower trace and the "B" sweep output on the upper trace. This clearly shows the appropriate delay of the X-Y Display vertical sweep.

Figure 8. Vertical sweep timing coordination. Vertical scale: 2 volts/cm, horizontal scale 1 msec/cm.

A variable voltage supply was used to control the horizontal orientation of the display sweep. As the transducer/hydrophone array was advanced along its trajectory the horizontal display position was changed a proportional amount.

By utilizing this display technique the range in the acoustical field was made proportional to vertical position of the display trace and azimuthal or trajectory position was made proportional to horizontal display trace position.

To record this data a Polaroid Speed-Graphic camera was used. In order that a transparency and a positive print could be simultaneously obtained Polaroid Type 55 P/N was employed. This film produces both a negative transparency and a positive print with each exposure.

Each line of the hologram was exposed separately. The X-Y Display cathode beam was first slightly defocused in the horizontal dimension to produce horizontal beam dimension such that when advanced on consecutive sweeps it would completely transit the horizontal dimension of the cathode ray tube in approximately 50 sweeps with neither missed nor overlapped zones.

A single exposure would be taken and then both the transducer/hydrophone assembly and the X-Y Display beam trace would be advanced a proportional amount prior to the next exposure. By repeating this technique on the order of 50 times a coarsely sampled quasi-hologram was permanently recorded on the film. The results of some of these recordings are given in Figures 17 and 18 in the Data and Results section of this report.

The actual tank, which was constructed of ¼ inch plywood and fibreglassed to insure water-tight integrity, measured 1.2 x 2.4 x 0.28 meters.

In order to reduce multiple echoes in the tank the entire interior of the tank was covered with $\frac{1}{4}$ inch rubber foam material of the type used to make dry SCUBA Suits. A picture of the physical arrangement of the experiment is presented as Figure 9.

Figure 9. Overall view of experimental arrangement.

An aluminum cart was constructed to hold and position the pulse transmitting transducer and the receiving hydrophone. This cart was mounted on a two-rail system which enabled the transducer/hydrophone assembly to be mobile throughout the volume of the tank, however, during the quasi-holographic recording the cart was held stationary in the range or length dimension while the transducer/hydrophone assembly was made to make a controlled discrete transit in the azimuthal or width

dimension. Figure 10 gives an overall view of the cart and Figure 11 is a closeup of the transducer/hydrophone assembly position measuring apparatus.

Figure 12 is a front view of the transducer/hydrophone assembly.

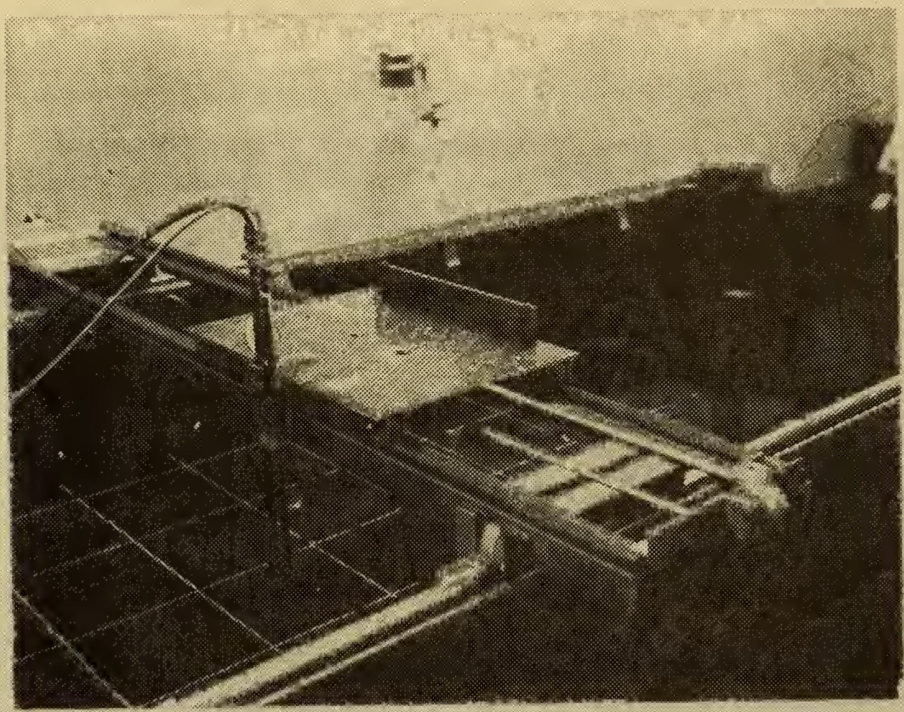

Figure 10. View of transducer/hydrophone assembly positioning cart.

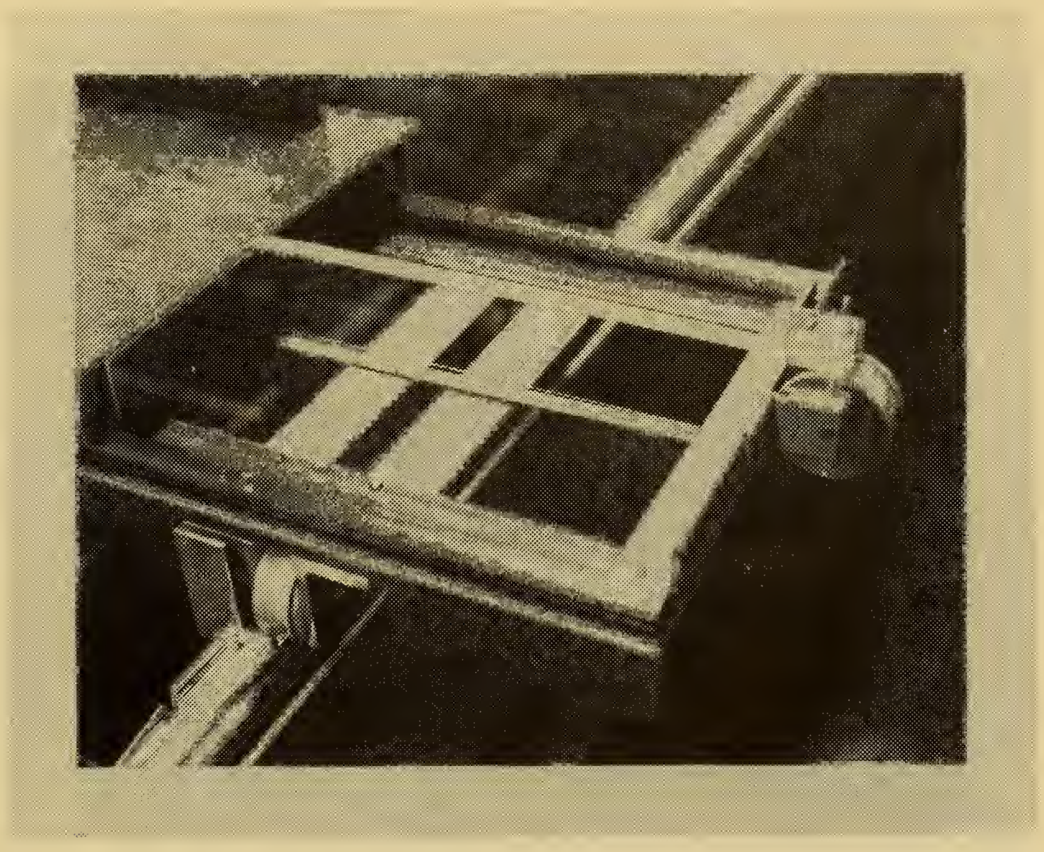

Figure 11. Closeup view of transducer/hydrophone assembly position measuring apparatus.

Figure 12. Front view of transducer/hydrophone assembly arrangement.

## IV. DATA AND RESULTS

As the thesis progressed it became obvious, due to the limited time available, that this thesis should concentrate on the physical construction of experimental apparatus and conclude with the physical recording of the quasi-hologram. It is anticipated that the imaging portion of this investigation will be the subject of subsequent work.

With this understanding it was decided that the test which would be utilized to determine if actual quasi-holographic information was being recorded would be to perform a recording evolution in which the target geometry was sufficiently simple to mathematically determine what its quasi-hologram should be. This was done utilizing the target geometry represented in Figures 13 and 14. First the mathematical modeling was done to determine the pattern which should be detected and then a recording evolution using a physical representation of the mathematical model was done. The results of this recording were compared with the predicted results to determine system recording effectiveness. This testing was done several times with favorable results an example of which follows.

For the geometry depicted in Figure 14 the lead target acts as if it were a line reflecting source. Since the reference signal is coherently summed with the reflected signal as detected along the transducer/hydrophone trajectory constructive interference should occur whenever C differs from A by an integral number of wavelengths $\lambda$ . Or in terms of azimuthal position B, these maxima should occur at

$$B_n = \pm \left[ (A + n\lambda)^2 - A^2 \right]^{1/2} \qquad n = 1, 2, 3, \cdots$$

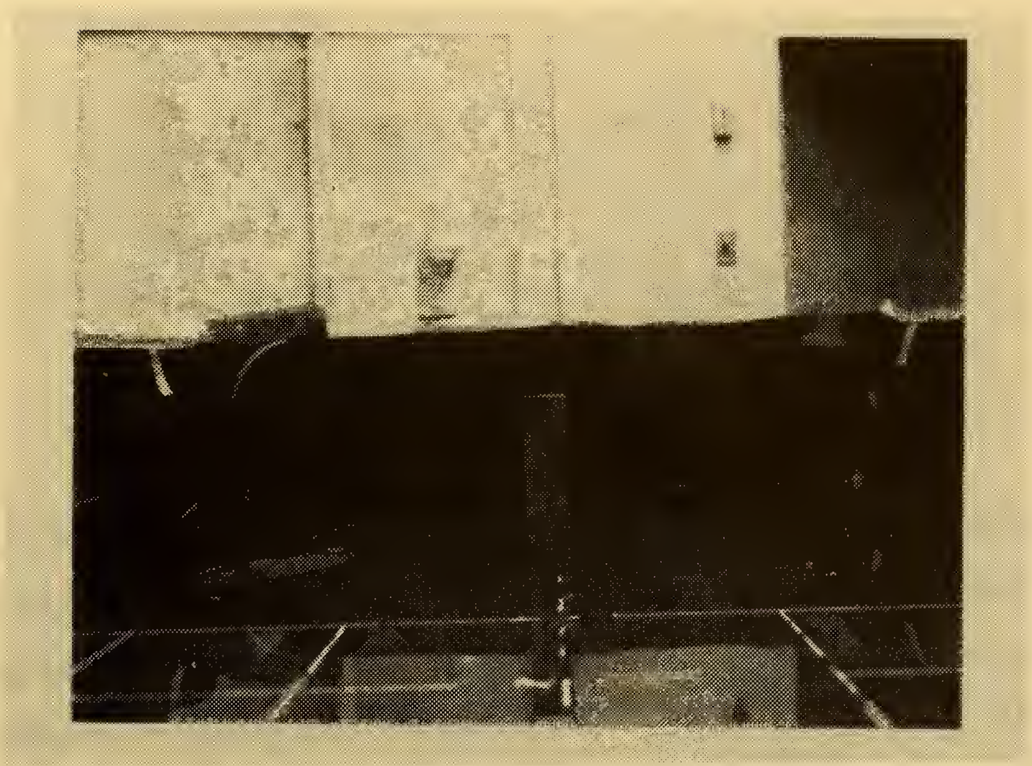

Figure 13. Visual picture of actual test geometry. (Target of interest is the 2x2x8 inch lead brick located in the approximate center of this picture)

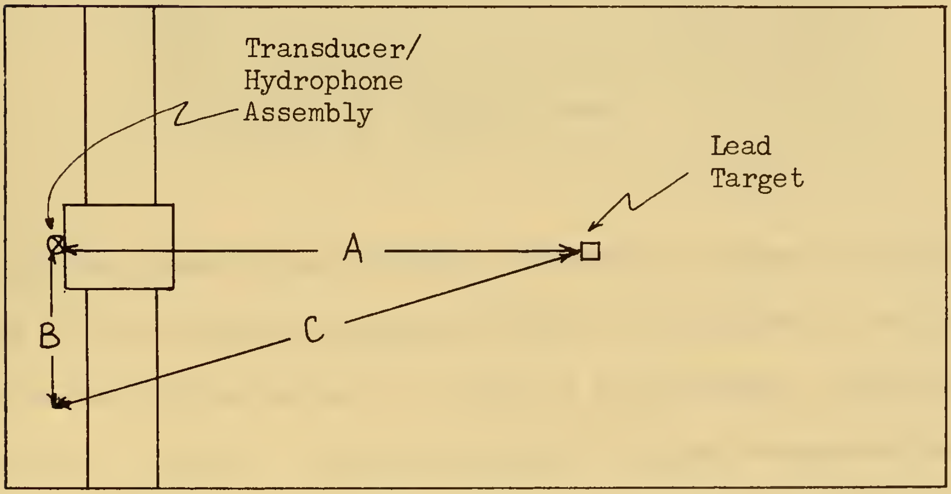


Figure 14. Typical test geometry for verification test.

For the particular verification which follows the following listed parameters were pertinent

$$f = 563.317 \text{ KHZ}$$

$$\lambda = 0.26628 \text{ cm}$$

$$A = 100 \text{ cm}$$

On each successive sweep of the cathode the transducer/hydrophone assembly was advanced 0.3175 cm (1/8 inch). Figure 15 is the quasi-hologram that was recorded. In this recording the film was overexposed to enhance the visibility of constructive interference fringes. An example calculation for $B_1$ follows and a summary comparison is given in Table 1.

$$B_1 = \pm \left[ (100 + 0.26628)^2 - (100)^2 \right]^{1/2} \text{ cm}$$

$$B_1 = \pm 7.03 \text{ cm}$$

Note the Fresnel zone structure evident at a range of 100 cm in Figure 15. For this interference pattern the location of the central, first and second maxima are, in terms of sweep number, respectively 43, 20 and 66, 11 and 75. It was determined that the transducer/hydrophone assembly could be positioned accurately to with ± 0.3 cm.

The target used for this verification consisted of a lead brick with dimensions of 2 x 2 x 8 inches.

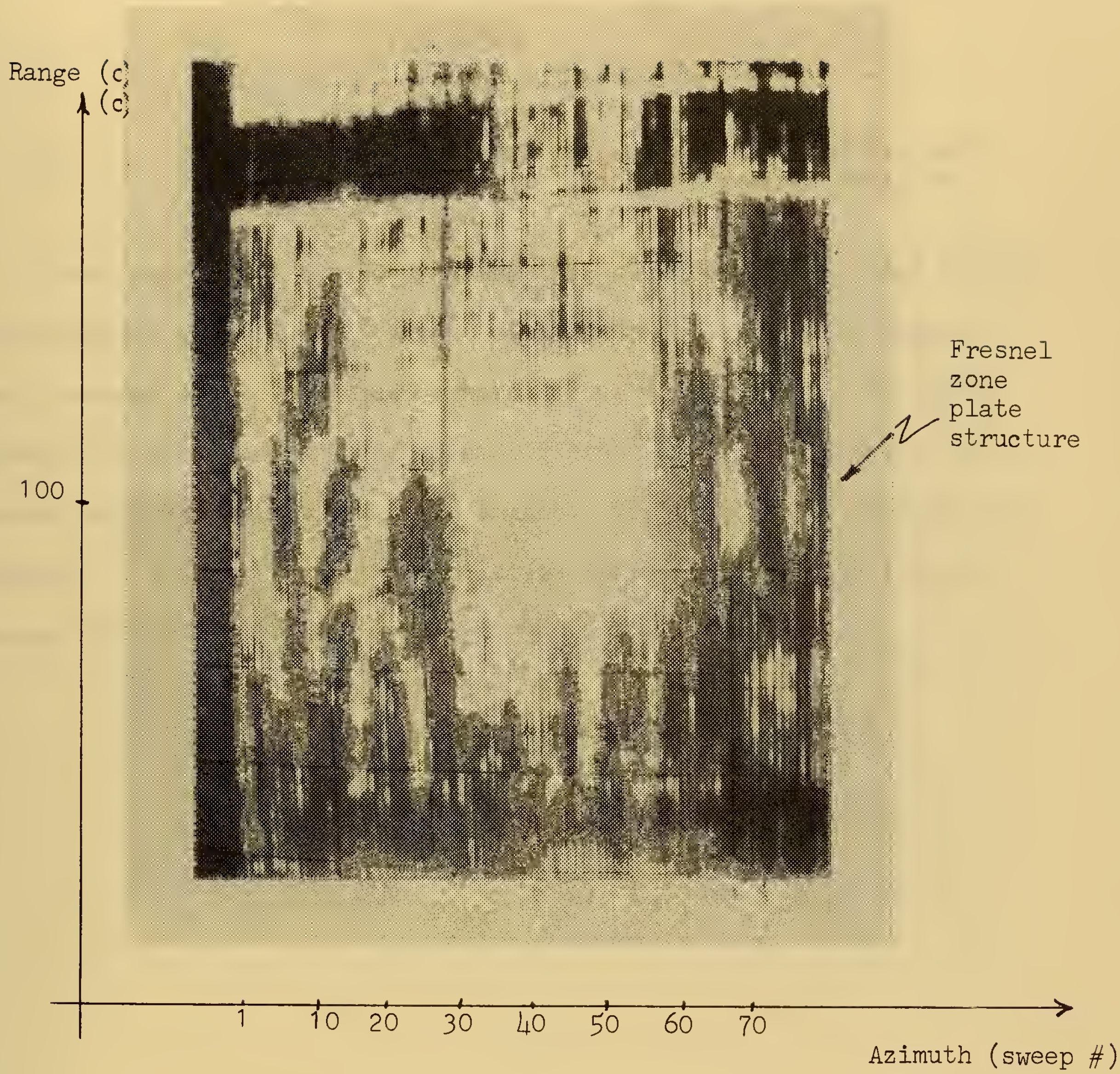


Figure 15. Quasi-holographic recording of target geometry depicted in Figures 13 and 14. (Data for calculations was taken from pattern located at range coordinate 100 cm)

| | calculated (cm) | measured (cm) |
|---|---|---|
| $B_1$ | 7.303 | 7.3 ± .3 |
| $B_2$ | 10.330 | 10.2 ± .3 |

Table 1. Comparison of calculated position of constructive interference maxima with experimentally measured position.

As an example of the quasi-holographic information recorded by this experimental technique the target configuration depicted in Figure 16 was recorded at two different ranges. The targets in this following example consisted of a 4 inch diameter brass ball and a stack of lead bricks with dimensions 2 x 8 x 8 inches. The results are presented as Figures 17 and 18. Note the similar patterns produced with only the range information changed.

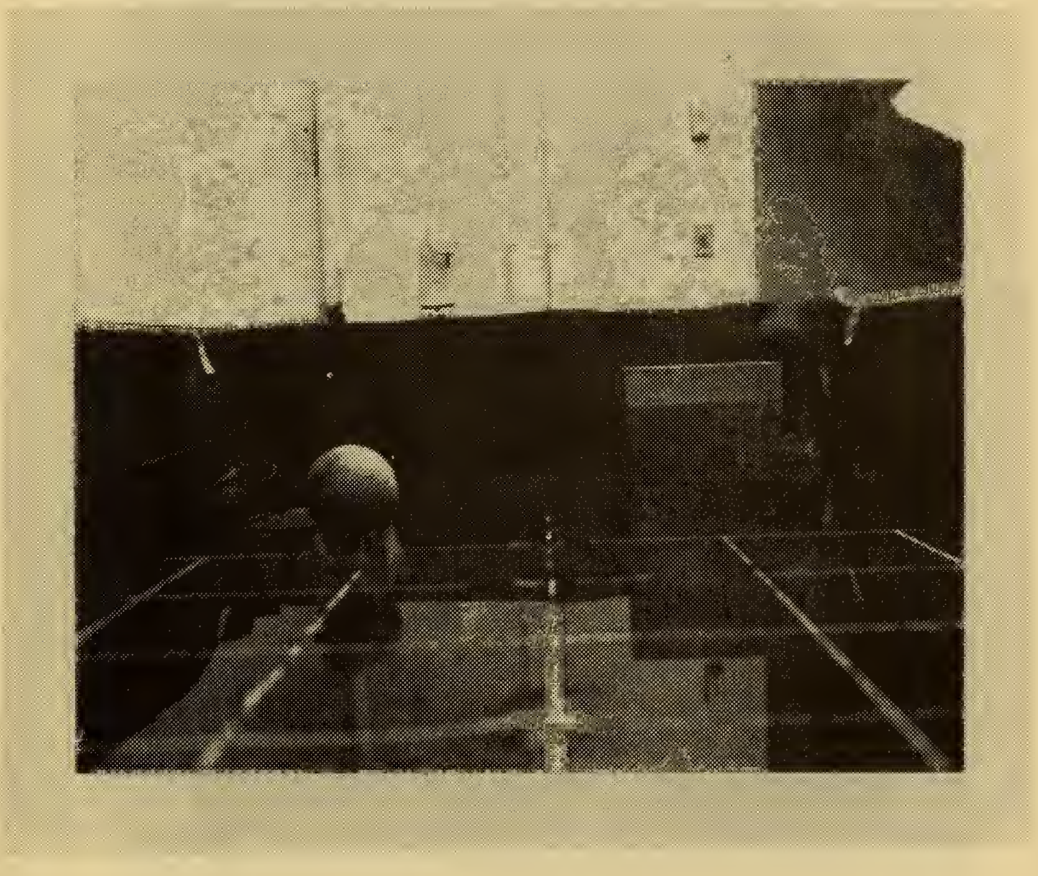

Figure 16. Visual view of target area as seen from the center of the transducer/hydrophone assembly trajectory. The targets of interest are the brass sphere located left center and the lead brick located right center.

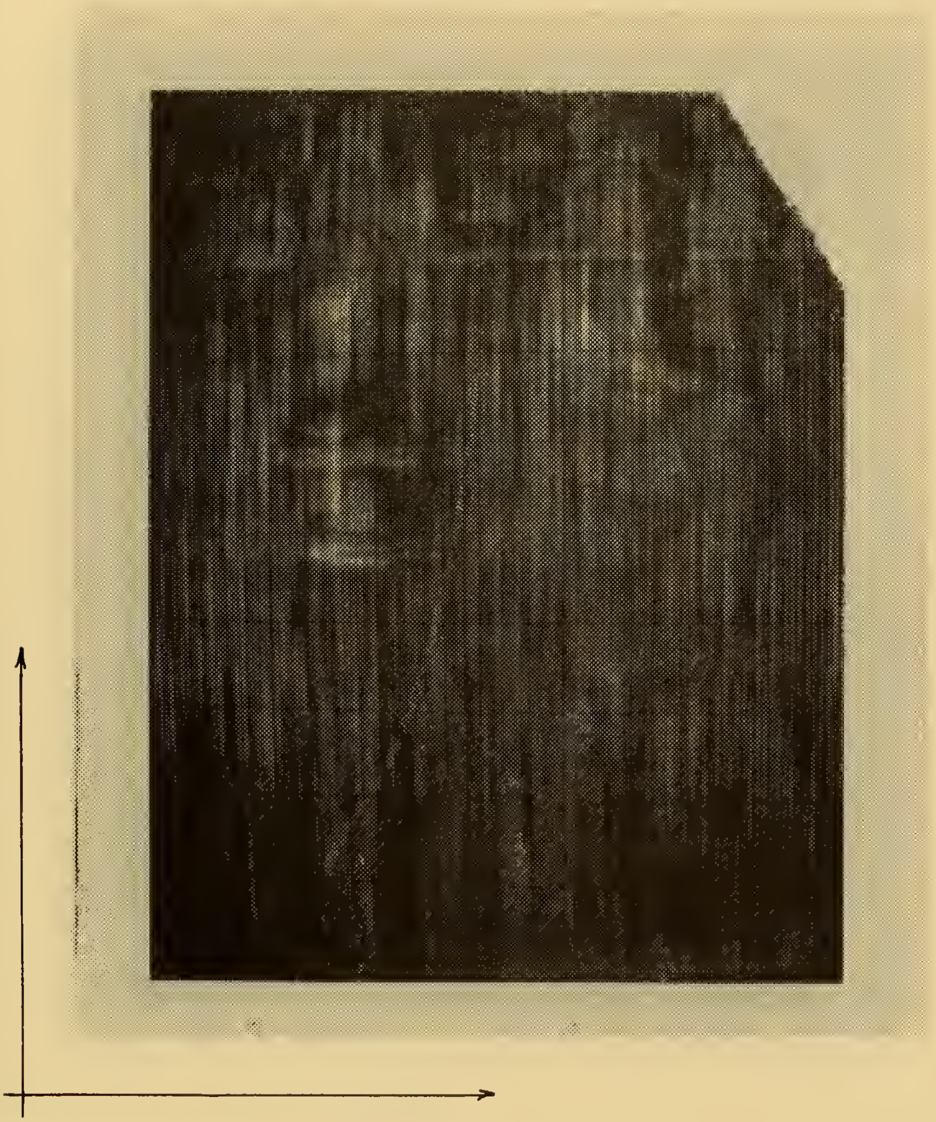

Figure 17. Quasi-hologram of target configuration depicted in Figure 16. Range to brass ball approximately 110 cm.

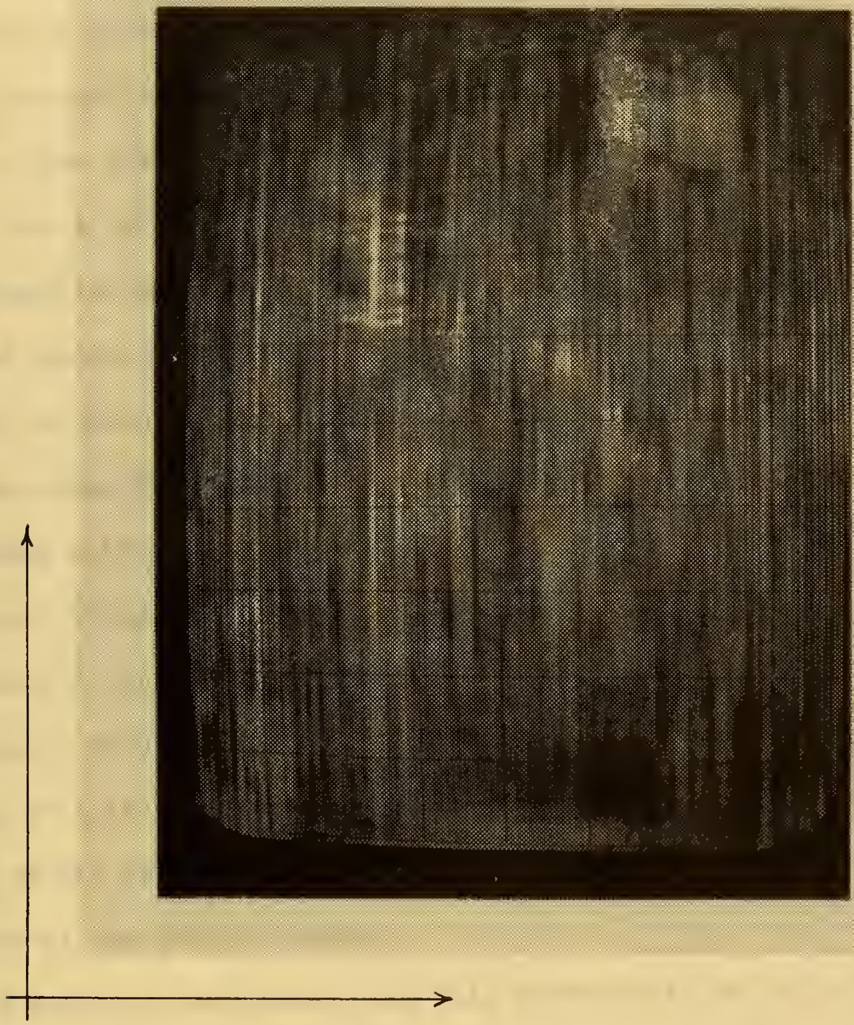

Figure 18. Quasi-hologram of target configuration depicted in Figure 16. Range to brass ball approximately 140 cm.

## IV. CONCLUSION

It is felt that the object of this experimental investigation was achieved: that object being to construct a laboratory system capable of imaging acoustical data which possesses the capability of being scaled for future open ocean application.

Although the imaging portion of this investigation was not completed due to time limitation it is felt that it has been amply demonstrated that such a coherent, side-looking sonar imaging system could be achieved. It should be noted that such an imaging system is currently well advanced in the microwave radar region. Such a system could be a contribution to ocean exploration by providing a system whereby static contours of the ocean bottom could be easily imaged to yield a visual picture of existing bottom configuration over far greater ranges than is currently possible using optical methods. Since acoustic reflection requires interfaces of differing acoustical impedances such a system could prove extremely valuable in the search for undersea mineral and oil resources. Also, this imaging technique could prove invaluable for the locating of some of the salvageable material which now remains undetected in the depths of the world's oceans.

A possible improvement for this sytem would be to include a detector after the summing network. This would provide the signal envelope, which contains the image information, as the cathode ray intensity modulating signal.

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. ABSTRACT


A side-looking sonar system which utilizes coherent electrical processing is investigated. Such a system produces a quasi-hologram of the reflected sound field which may be subsequently imaged to give a visual presentation of the insonified region.

An actual working laboratory system is constructed and several quasi-holograms are depicted in the Data and Results section. Imaging is not completed, however, an optical processing arrangement to accomplish this task is presented.

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
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| Holography | | | | | | |
| Synthetic-Aperature | | | | | | |
| Sonar | | | | | | |
| Imaging | | | | | | |
| Acoustic Imaging | | | | | | |
| Resolution Enhancement | | | | | | |

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